Analysis of postural control adaptation during galvanic and vibratory stimulation.

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Abstract

The objective for this study was to investigate whether the postural control adaptation during galvanic stimulation of the vestibular nerve were similar to that found during vibration stimulation to the calf muscles. A method for adaptation analysis was used to analyze the evoked changes of posture, stimulus responses and the motion dynamics.

The adaptive adjustments of postural control were similar during galvanic and vibratory stimulation, which suggests that the adaptation operate in the same way independent of the receptor systems affected by the disturbance. There was however a difference in the dynamic feedback properties of the measured responses.

Introduction

If a repeated disturbance of postural control becomes more intense, it usually initiates an adaptive process to improve the control performance (1-3). However, it is unknown whether this adaptive process is similar independently on receptor system affected by the disturbance. The adaptive adjustments were therefore analyzed during posturography with perturbations induced by disturbances of vestibular and proprioceptive information.

The adaptive adjustments in postural control were quantified by a method approach describing postural control as a dynamic feedback control. The method provides a mathematical model of the relationship between induced disturbances and counteractive body sway responses (4).

The aim of this study was to investigate if the adaptive processes and motion response dynamics were similar whether perturbed by galvanic or vibratory stimulation.

Methods

Galvanic stimulation of the vestibular nerve was performed on 12 test subjects (6 men, 6 women; mean age 41 years, range 23-56 years). Vibratory stimulation was performed on 10 healthy subjects (6 men, 4 women; mean age 37.5 years, range 29-56 years).

The galvanic vestibular stimulation was applied as bipolar and binaural square pulses of 1 mA amplitude with pseudorandomly shifting polarity. The pulses were delivered by a constant current generator through two electrodes placed on each of the mastoids. Vibratory stimulation was applied to the gastrocnemius muscles of both legs. The vibratory amplitude was 1.0-mm and the frequency 85 Hz. Forces and torques actuated by the feet were recorded by a force platform and data were sampled at 10 Hz.

The subjects were told to stand erect but relaxed and feet at an angle of about 30 degrees. Spontaneous sway was recorded for 30 seconds of quiet stance, after which the vibrators for 200 seconds were turned on and off according to a pseudorandom binary sequence (PRBS) containing pulses varied between 0.8 to 6.4 seconds. The experiments were conducted both with eyes closed and open.

Analysis

The measured lateral torque during galvanic stimulation and anteroposterior torque during vibratory stimulation was analyzed with a method considering the adaptation of postural control. The method aims to describe the adaptation of the slow posture motion as well as the adjustments of the stimulation responses. This information is used to estimate a time-invariant

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feedback control model that mathematically describes the relationship between the stimulation and measured body sway responses (4).

Posture and stimulus adaptation

Two exponential functions were used to describe the amplitude and time constants for the adaptive changes. The "Stimulus adaptation" function describes the adaptive changes in stimulus-response amplitude over time and the "Posture adaptation" describes the slow adaptive changes of posture.

Feedback model dynamics and motion complexity

A feedback model, optimized to describe of the stimulation – body sway response relationship, evaluated the complexity of the body sway responses and latency between the perturbations and the motion responses. The body motion dynamics were also evaluated from the feedback model in terms of three dynamical parameters: swiftness, stiffness and damping.

Modeling of adaptation

Time-series analysis using the maximum-likelihood method was used to fit an input-output model of the stimulus-response data obtained in experiments. Model validation was made using ANOVA-based residual analysis at a significant level of $p<0.05$. Generalized autoregressive heteroscedastic (GARCH) modeling was applied to fit exponentials describing the adaptive changes of variance in the course of the experiment.

Statistical analysis

The differences between the galvanic and vibration tests were analyzed with Mann-Whitney non-parametric test and the difference between tests performed with eyes closed-eyes open was analyzed with Wilcoxon non-parametric test.

Results

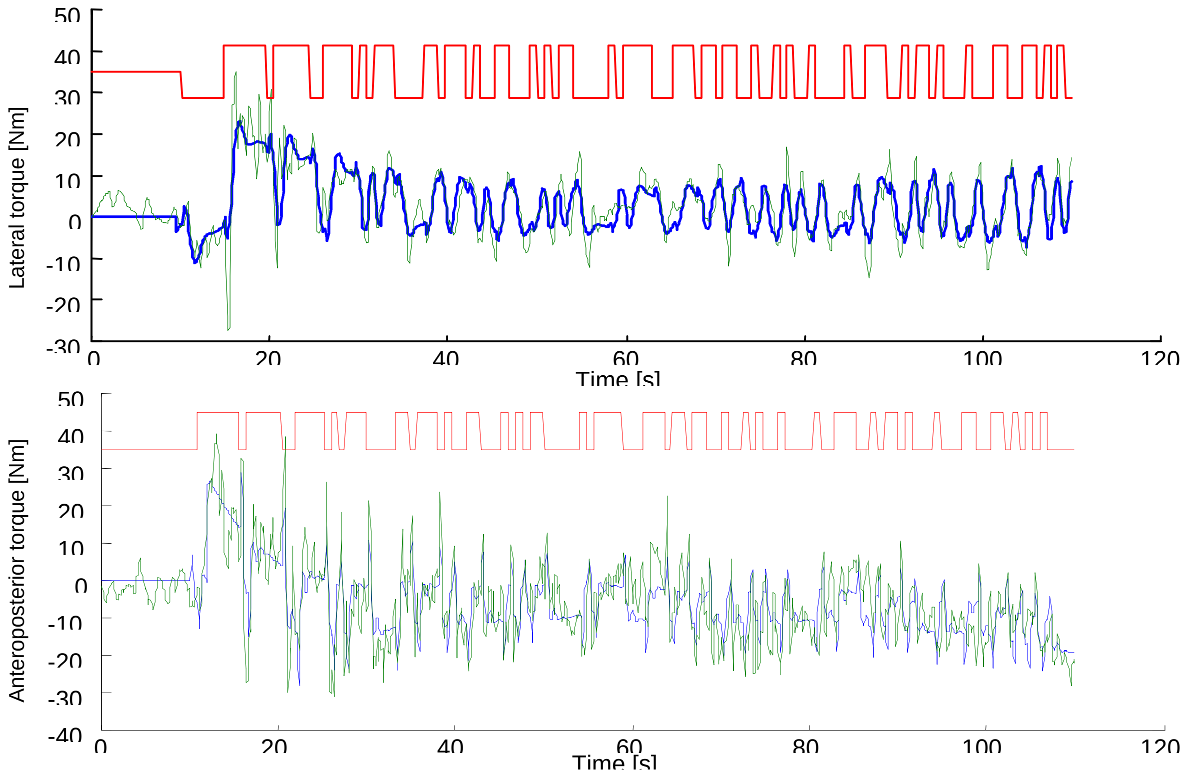

Figure 1. Measured torque (thin dotted line) in the lateral and anteroposterior direction from experiments with galvanic and vibratory stimulation respectively. Positive values correspond in the top figure to a rightward position whereas positive values in the bottom figure correspond to a backward position. The top curve shows the stimulation, which is arbitrarily scaled and moved. The model simulation values are marked with a thick line. Note the similarities between body sway induced by the galvanic and vibratory stimulation and the high accuracy of the model simulation when measured body sway is described with the analysis method.

Posture and stimulus adaptation

A. Posture adaptation		Amplitude A_1 [Nm]	Time constant τ_1 [s]	Adj. complexity (2,1,0) [%]
Galvanic	Closed	49.4 (65.5)	13.6 (16.6)	(50, 33, 17)
	Open	125.5 (253.4)	20.0 (21.7)	(58, 25, 17)
Vibration	Closed	24.6 (20.6)	5.8 (6.6)	(40, 50, 10)
	Open	94.3 (124.4)	11.5 (11.3)	(70, 20, 10)

B. Stimulus adaptation		Amplitude A_1 [Nm]	Time constant τ_1 [s]	Adj. complexity (2,1,0) [%]
Galvanic	Closed	99.9 (194.4)	15.8 (22.4)	(50, 50, 0)
	Open	60.6 (183.3)	13.3 (24.3)	(50, 50, 0)
Vibration	Closed	37.4 (47.0)	3.8 (2.4)	(90, 10, 0)
	Open	30.3 (47.0)	7.5 (14.3)	(60, 40, 0)

Table 1: Mean and standard deviation (SD) for the absolute amplitude and time parameter values across subjects obtained from the “Posture adaptation” (A) and “Stimulus adaptation” (B). The adjustment complexity shows the rate of (second, first, zero)-order adjustment pattern i.e. if both, one or none of the function terms are of considerable influence when describing the adjustment pattern.

The variations in amplitudes and in the adjustment complexity indicate a large inter-individual variation in the way the adaptive adjustments was done. However, the time constants were within the same range and both posture and stimulation responses were usually adjusted. There were no significant differences in amplitude and time constant parameters in the “Posture adaptation” and “Stimulus adaptation” functions between any of the test conditions.

Feedback model dynamics and motion complexity

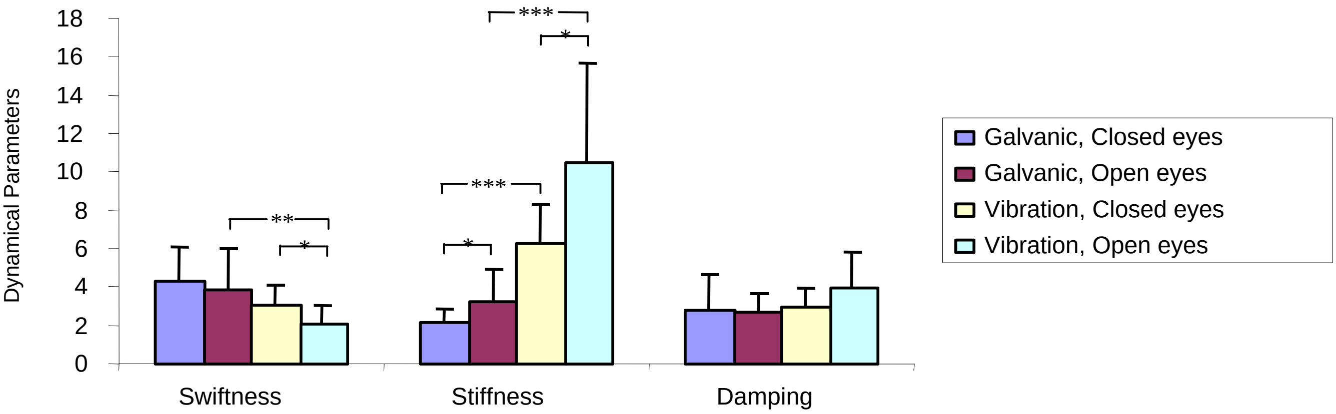

Figure 1. Mean and standard deviation values for the dynamical parameters swiftness, stiffness and damping. One asterisk denote a significant difference (p<0.05), two asterisks a difference (p<0.01) and three asterisks a difference (p<0.001).

The dynamical parameter values show that the body sway responses were somewhat more rapid to the perturbation during galvanic stimulation compared to during vibratory stimulation, but the responses to the induced body deviation were not as strong. The responses to the galvanic stimulation were less affected by visual input compared to during vibratory stimulation.

Modeling of adaptation

Significant differences were found between variance properties of eyes-closed and eyes-open conditions, respectively. The test subjects consistently exhibited longer GARCH correlation time for eyes closed as compared to eyes-open condition for all stimulus conditions. With one exception only among the test subjects, a low-order GARCH model (n=1-3) was sufficient for accurate modeling of volatility behavior in response to change in stimulus condition.

Discussion

This study demonstrated that the adaptation of postural control induced similar adjustment patterns both during galvanic and vibratory stimulation irrespective of whether the motion responses were induced in lateral or anteroposterior direction. These body sway adjustments could be described by a method, which incorporated the adaptive adjustments both of posture and the feedback dynamics of postural control.

The adaptive responses induced by the repetitive galvanic or vibratory stimulation contained at least two separate processes (4). One process can be seen in the progressive reduction of body sway during the stimulation. An additional slower simultaneous adaptive process can be seen in the postural displacement. There was a variation in the way the adjustments were done, but there was always an adaptive adjustment in the stimulation response and mostly in the posture responses as well.

However, the dynamical properties were found to be different between galvanic and vibratory stimulation, reflected by altered response latencies and altered dynamical properties. Some of these results might be explained by the difference in lateral and anteroposterior biomechanical constraints. Binaural galvanic stimulation with a 1-mA current might also affect postural control less than high intensity vibration does.

The GARCH correlation time was longer with eyes closed as compared to with eyes open for all stimulus conditions. This might be an indication for that the capacity of adaptation to stimulus or perturbation is lower with closed eyes.

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